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Nano Silica and Nano Titania Multifunctional Additives in Water based Muds for Torque and Drag Reduction

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Abstract

This paper describes the effect of using nano Silica and nano Titania in water-based drilling fluids to address the challenges associated with conventional drilling fluids such as stuck pipe wellbore instability poor filtration properties and etc.

Performance of using these materials with low concentration in comparison with conventional drilling fluids were tested and interpreted in a laboratory study Rheological tests API/HPHT filtration tests Lubricity tests and Differential Pipe Sticking tests for two concentrations (05 %wt and 1 %wt) of nano materials have been performed. Also in some tests hot-rolling process for fluids in 250°F for 4 hours at dynamic condition was performed to simulate mud circulation in field operation. A polymeric drilling fluid and a bentonite mud were considered as blank muds to finding effect of nanomaterial on them.

Based on test results proposed nano fluids were capable of reducing API/HPHT fluid loss spurt loss and built a mud cake with optimum thickness and integrity that can prevent problems such as differential stuck pipe and wellbore instability while drilling. Adding 05% wt of nano Silica or nano Titania showed excellent effect on reducing friction loss of formed mud cakes and torque problem also built mud cakes had smoother and more compacted surface with very low thickness. These improvements happen because proposed particles mostly fill the micro/nano pores on the mud cake surface. Using 1% of proposed materials improved drilling fluids even more but may be it is not cost-effective.

Novelty of this research is due to performing laboratory sticking pipe test on proposed nano materials for the first time. Also effect of proposed nano materials on drilling fluid parameters were tested and analyzed at the same time.

Keywords: Drilling; Nanofluid; Nano silica; Nano titania; Laboratory evaluation; Stuck pipe

Introduction

Drilling fluids have very important role in success rate of drilling operations. This role can be explained through transportation of cuttings cooling and lubricating of the bit torque and drag reduction stabilization of the open boreholes control of fluid loss control by forming proper filter-cake on wellbore side and etc.

OBMs were very popular drilling fluids because of having minimum operational problems during drilling and also minimum formation damages. In fact OBMs are best choice because of their stable properties but nowadays due to more attention on environmental and also cost issues it is tried to using WBMs instead of OBMs to make drilling fluids more safer and cheaper. But if WBMs can't provide needed properties like OBM systems can cause serious drilling fluid-related problems such as bit balling stuck pipe borehole instability torque and drag etc. Today based on numerous improvements on nanotechnology and their wide applications on different industries using nano materials are getting common in oil industries too. Drilling fluid can use nanoparticles as a winning card in fulfilling its responsibilities. Enhancing the mud cake structure lowering the spurt water loss improving lubricity properties are just some examples of nanoparticle improvements in drilling fluid industry. Drilling fluids that contain at least one additive with particle size in the range of 1-100 nano-meters are defined as nano-based drilling fluids. A nano sized particle dimension is one billionth of a meter Nano sized materials have very high surface area to volume ratio compared to the macro and micro-sized materials and this property helps for enhancing drilling mud properties [1].

Researchers have tried nano-additives for enhancing drilling fluid properties so far:

Mohd Taha et al. performed some Laboratory test to indicate that nano graphen effect on lubricity ROP enhancement and retained permeability. They concluded that nano graphen can reduce torque up to 80% on conventional salt polymer mud and up to 50% in HTHP WBM Also using 3% of the nano graphen can achieve 41% of retained permeability whereas base mud only achieves 5% of retained permeability without any breaker solution.They used nano graphen in field operation in a HTHP onshore with temperature up to 176°C (349°F) and it was shown that 2-3% of nano graphen had improved ROP 125% actual torque reduction of 20% and improve bit's life span about 75% Nano graphene also enhanced API Fluids Loss too; this was referred to synergy between the nano graphene materials and the polymeric fluids loss controllers Mohd Taha et al. also claimed that nano graphen particles change the morphology and surface characteristics of metal surface and build a self-healing friction barrier on metal surfaces. Nano graphen is also has another advantage that low concentration of it is required. Writers also claimed that some nano materials can eliminate spurt loss of drilling fluid and reduce formation damage in damage prone oil and gas reservoirs [2].

Jung et al. investigated iron oxide nanoparticles for improving rheological and filtration properties at HTHP conditions in water-

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based drilling fluids. They investigated two concentrations of the nanoparticles (05% wt and 5% wt) and as a result concluded that oxide nanoparticles distributed within the clay particles allowing forming links between Bentonite particles that cause high gel strength within the bentonite particles. Also the results showed nanoparticles had adverse impact on filtration properties of the treated muds [3].

Salih et al. investigated impact of three anionic nano materials (nano Silica nano Titania and nano alumina) in laboratory. They performed API experimental and rheological tests for all sample then a commercially available software was used for the hydraulic evaluation to simulate the impact of these nanoparticles on the equivalent circulation density and drill pipe circulation pressure in a symbolic directional well. They concluded that significant improvements in the rheological and hydraulics properties of the flocculated water-based muds happens when they are treated by 01% wt or less of nano Silica and 03% wt or less of nano titania and nano alumina. For the higher concentrations no more improvements were reported. Also between these nanoparticles only nano Silica and nano Titania were able to reduce the filtration volume. However all the nanoparticles enhance the mud cake structure. They claimed that all proposed nano materials can prevent/reduced drilling problems such as stuck pipe wellbore instability based on their hydraulic evaluation with software [4].

Contreras et al. laboratory investigated on impact of iron and calcium nanoparticles on the filtration property and lubricity enhancement of oil-based muds. Three concentrations (05%, 1% and 25% wt) of each type were chosen LPLT and HPHT filtration tests were performed to test the blends in the presence of graphite at low and high concentrations. The results show that 100% filtration reduction was achieved for the LPLT test based on using 1% wt of iron-based nanoparticles. For the HPHT tests 76% reduction was achieved with 05% wt of iron-based nanoparticles. Also they claimed that 38% and 59% friction reductions were achieved based on the calcium-based nanoparticles and iron-based nanoparticles respectively due to lubricity improvement [5,6].

Ismail et al. investigated on 30 nm MWCNTs in three concentrations (0001, 001 and 01 ppb). In their experimental research LPLT and HPHT filtration and rheological tests were performed and three temperatures (80°F, 200°F and 250°F) were also chosen for investigating of temperature effect on abovementioned properties MWCNTs did not show any improving effect on WBM rheology. Also 001 ppb of the MWCNT resulted in lowest filtration for both tests [7].

Mirzaei Paiaman et al. proposed using of carbon black nanoparticles in drilling mud to decrease probability of stuck pipe. They claimed that carbon black particles with Nanometer size particles causes to form a mud cake which is very continues and integrated (with low permeability) that is less prone to cause high volume of filtrate and thick mud cake. Less contact area between drill string and mud cake causes less resisting for motion and less probability of pipe sticking [8].

Javeri et al. showed in laboratory tests that presence of silicon particles reduces the thickness of the mud cake and claimed particle size distribution of silicon particles provided better uniform mud cake which restricted the flow of liquids from the drilling fluid to formations. They showed using 3% of silicon nanoparticles (by volume) can cause reduction in mud cake thickness by 34 percentage and also rheology parameters (PV and YP) is approximately stable but a little reduced [9].

Most of the focus on this paper is to reducing mud cake thickness and lessen differential sticking problem. The pulling force required for freeing a stuck pipe also increases with increasing mud cake thickness.

Isambourg and Matri showed how the magnitude of pulling force that is necessary to free a stuck pipe changes with a change in mud cake thickness [10].

Having less mud cake thickness can decrease probability of stuck pipe Drill string stuck problems usually caused by the drill pipe sticking to the mud cake on the wall of the wellbores due to high filtrate loss in wall of the wellbore or due to settling of cuttings into the wellbore when drill fluid circulation is stopped (Figure 1) [8].

Most incidents of stuck pipe are caused by differential pressure effects Excessive differential pressures across the lower-pressure permeable zones can cause the drill string to be pressed on the wellbore wall and sticking happens. This problem will be more drastic if drill string remains motionless for a long period of time. The difference between pressure of the hydrostatic pressure and the formation pore pressure forces cause drill string to get stuck to the mud cake. The causes of stuck pipe are commonly because of Key-seating high thickness of mud cake or seepage loss circulations [8]. Also Amanullah, Tan and Amanullah showed how different mud additives can affect the physio-mechanical properties of mud cakes and consequently on borehole problems [11,12].

Methodology

Drilling fluids preparation

A simple polymeric mud was used for initial formulation of blank fluid It includes fresh water salts viscosifiers and fluid loss controllers (mud #1). After mixing required mud additives in the fluid phase the pH of the mud was adjusted to 95-105 using NaOH to keep the mud in alkaline range and make bacterial degradation less probable. This blank mud was used as a representative of a microsized particle containing drilling fluid to use for comparative evaluation of rheological HPHT/API filtration and mud cake thickness properties of the nano-based fluids.

Also a bentonite mud (mud #6) was used as a simple drilling fluid for comparison and evaluation of lubricity and sticking pipe properties of the nano-based drilling fluids that are studied in this paper.

Nano-drilling fluid

The nano-fluids (Mud#2 to #5) and (Mud#6 to #10) have the same formulation as Mud#1 and Mud#6 in addition with SiO_2 and TiO_2 nano-additive with concentration of 05 and 1% w/w respectively XRD

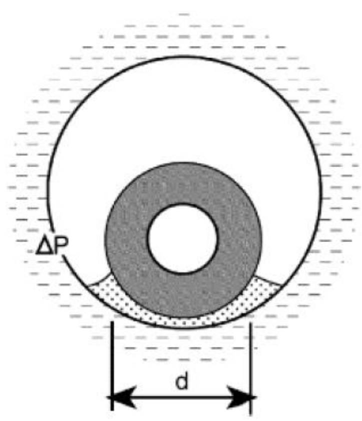

Figure 1: Differential Stuck Pipe because of high mud thickness [8].

of used nano materials are given in Table 1. Formulation of tested drilling fluids is given in Table 2.

Experimental tests

Experimental tests have been performed in the following order:

A) Rheological tests

B) API/HPHT filtration tests

C) Lubricity tests

D) Differential Pipe Sticking tests.

Hot rolling of fluids in 250°F for 4 hours at dynamic condition was performed to simulate mud circulation in field operation.

Rheological measurement tests were performed for each sample before hot rolling (BHR) and after hot rolling (AHR) Rheology measurement at 600 rpm 300 rpm 200 rpm 100 rpm 6 rpm and 3 rpm were read for all of the sample muds.

The rheology performance of the mud systems can be discussed in three important parameters (PV and YP) PV shows the mechanical frictions between the solid phases liquid phases and solid and liquid phase YP shows the electro-chemical or attractive forces in mud under flowing conditions. This is result of negative and positive charges located on or near the particle surfaces.

API/HPHT filtration tests for each sample were performed at ambient temperature and at the pressure of 100 psi and the filtrate volume collected in 30 minutes were reported as API filter loss of fluid (cc) also HPHT filtration tests for each sample were performed at 250 Fahrenheit temperature and at the pressure of 500 psi the filtrate volume collected in 30 minutes were reported as HPHT filter volume loss of fluid (cc). The spurt loss was measured and recorded at time zero for each test. During test process a mud cake was developed on a filter paper. After 30 minutes the mud cake thickness was measured in millimeters for each test.

The lubricating parameter of the sample drilling fluids were measured using the OFITE lubricity tester Lubricity. Tester has a metallic ring that is fitted in the main shaft to simulate a piece of the rotating drilling string a metallic test block with curved face fitted in the test block holder to simulate a piece of the static casing string a sample cup to place the drilling fluid sample a sample cup stand to place the cup and raise it to fix at an appropriate location so that the rotating ring and test block assemblies are submerging into the fluid system while measuring the torque.

Element	Compound formula	Nano silica	Nano titania
Si	SiO_2	99.10%	-
Ti	TiO_2	-	99.25%
Na	Na_2O	0.15%	0.29%
K	K_2O	0.03	0.01%
Al	Al_2O_3	0.03	0.03%
Fe	Fe_2O_3	0.04%	0.03%

Table 1: XRD of nano silica and nano titania.

Components	Concentration (lb/bbl)				
	mud#1	mud#2	mud#3	mud#4	mud#5
Drill water	329	329	329	329	329
Potato Starch	6	6	6	6	6
PAC LV	1	1	1	1	1
Xanthan Polymer	75	75	75	75	75
Potassium Chloride	20	20	20	20	20
Nano Silica	-	87	-	175	-
Nano Titania	-	-	87	-	175

Table 2: Mud formulation for Tests part AB and C.

A motor provides the rotational speed during the measurement of the force. The force required to slide the metallic ring simulating a piece of the drill sting against the static test block simulating a piece of the casing is measured by the power required to turn the test ring shaft at 60 rpm. A belt guard placed to cover the driving belt improves the operational safety of the test apparatus during the measurement [13].

The equipment should be calibrated using 280 cc deionized water before each test to ensure data reliability and accuracy. If the test apparatus along with all associated parts are neat and clean and fault free then the typical dial reading of deionized water should be measured as 34 ± 2 at 60 rpm rotational speed and 150 psi applied torque Based on the deionized water reading a calibration factor (CF) is calculated using eqn. (1):

$$CF = \frac{34}{DW\,reading} \tag{1}$$

The coefficient of friction (COF) of the blank mud was obtained experimentally using the lubricity tester then the proper concentration of nanoparticles will be added to the blank mud and then measured the torque and calculated the COF using eqn. (2).

$$COF = \frac{CF \times Torque\ \text{Reading}}{100} \tag{2}$$

The coefficient of friction (COF) is a unit less number that indicates the mechanical interaction between two surfaces that are contacting each other to create an interface. The COF value measured in the lab indicates kinetic COF value that is encounter while drilling Kinetic COF is defined as the ratio of the force required to rotate a moving surface continuously against a static surface under the action of a normal force holding them together.

The less COF value represents fewer problems such as torque force while drilling operation. High COF value of drilling fluids means having more loss of transitional power torque and drag and stuck pipe issues. Reduction of the COF will provide better power transfer to the bit and increasing ROP while drilling operations [13].

D) Differential pipe sticking tests: The differential sticking tester measures the Stuck Pipe Tendency Coefficient of drilling fluids and also determines how effective lubricants (liquid or solid) might be with any drilling fluid. In this test a torque plate will be put over the md cake with hand pressure for 10 minutes then with spinner wrench a rotational spinning force will be applied for moving wrench on the surface on mud cake. The less reading value for spinning force indicates less torque problem and more efficiency of solid/liquid lubricant. With having measurement of the area of cake building during a test the Bulk Sticking Coefficient is obtained and can be read directly at the conclusion of the test. This coefficient takes into account both the friction or stickiness of the filter cake as well as the amount of cake building that would cause stuck pipe. The coefficient is determined by running a Timed Filtration test. By having the area of cake building during a test the "Bulk Sticking Coefficient" is obtained and read directly at the conclusion of the test with using of formula no 3. Tendency of fluid to creating a pipe stuck and how effectiveness of lubricants or nano materials can be determined by this test (Table 3) [14].

$$K_{sc} = \frac{(T_u) \times 0.001}{1 + 1.33 \times (H)} \tag{3}$$

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Components	Concentration (lb/bbl)				
	mud#6	mud#7	mud#8	mud#9	mud#10
Drill water	340	340	340	340	340
Potato Starch	20	20	20	20	20
PAC LV	14	14	14	14	14
Xanthan Polymer	40	40	40	40	40
Potassium Chloride	-	87	-	175	-
Nano Silica	-	-	87	-	175
Nano Titania	-	-	87	-	175

Table 3: Mud formulations for test part D (concentration of 05% and 1% wt).

Tu: Average of readings from Torque Wrench (psi)

Cake Height: Height above flat surface of cake around the edge of the plate (inches)

Ksc: Bulk Sticking Coefficient.

Testing equipment

All testing procedures and equipment have followed the API RP 13B-1 [15]:

- Mud preparation: Hamilton Beach Mixer
- Rheology: Fann 35 Viscometer Thermocup and Thermometer
- HPHT Filtration: Ofite HTHP Filter Press 175 ml HTHP filtration cells 3-in) filter paper (Diameter 25-in) high pressure N_2 supply
- API Filtration apparatus
- Roller Oven
- OFITE Lubricity Tester
- OFITE Differential Sticking Tester.

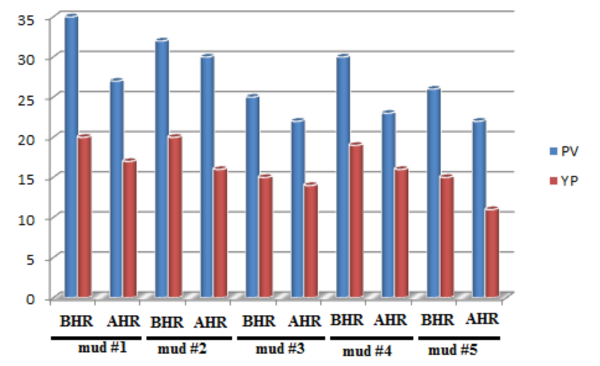

Figure 2: Rheological parameters changes with adding nanoparticles.

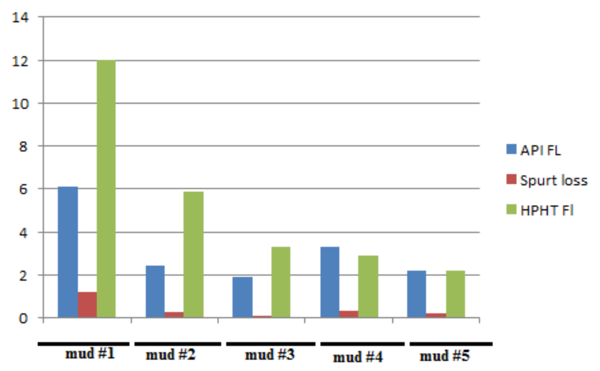

Figure 3: Filtration parameters changes with adding nanoparticles.

Results and Discussion

Test results and discussion about them are presented in Table 4.

Rheology performance comparisons

Similar mud rheological behaviors were observed for different nanoparticles Lower overall rheological values were obtained when compared to blank sample at both systems for BHR and AHR with adding nano materials. After Hot-Roll rheology parameters were reduced normally. Increasing nanoparticles concentrations reduced the rheology parameters (PV and YP). For instance adding 5% wt of nano Silica and nano Titania reduced the plastic viscosities from 35 to 32 cp and from 27 to 25 cp respectively. Considering the economics using 5% wt could be sufficient to reduce the plastic viscosity in the tested muds to the lowest values based on the case. The minimum plastic viscosity is normally favorable as it helps with reduction of energy loss due to decreasing mud friction and improving ROP Lowering YP is also can be favorable as probability of flocculation and excessive pump pressure loss decreases.

In fact proposed nanoparticles can be replaced in fluid formulations instead of deflocculant agents such as lignite or lignosulphonate without increasing solid amounts in the fluids or any change in mud density (Figure 2).

API/HTHP filtration test performance

Mud spurt loss is one of the major factors that can cause formation damage on reservoir zone. The minimizing of spurt loss of the nano-based fluids is a very crucial property of proposed nanofluids. By virtue of the huge surface area of the nano materials nanofluids had extremely low spurt loss properties that can improve drilling fluid performance .

Nano-additives with having superior plugging and sealing capacity can plug the filtrate paper pores and reduce filtration water (Figure 3).

Lubricity test performance

Proposed nano materials will change the morphology and surface characteristics of the metallic surfaces and build a low-friction barrier on interface surfaces. Proposed nano materials decrease contact area between metal surface and wellbore wall and minimize torque and drag issues in the well.

More so the smooth/compacted mud cake helps in reducing the stuck pipe by increasing the lubricity of mud. The mud cakes formed in filtration test were thinner in comparison with the blank mud.

The diameter of silicon and titanium particles ranges from 30-130 nanometers. This advantage of silica which has nanometer size particles causes to make a mud cake that is more integrated with less permeability so less volume of filtrate and therefore mud cake thickness is less than conventional muds.

The lubrication of proposed materials mechanism is controlled by chemical/physical structure of nano materials and their ability to form a strong-bonded film on the rock and metal surfaces. The nano materials will invade into the micron/nano sized spaces due to having small particles and chemically bonded to the metal surface. All tests

Sample no	mud#1		mud#2		mud#3		mud#4		mud#5	
Rheology parameters 120F	BHR	AHR	BHR	AHR	BHR	AHR	BHR	AHR	BHR	AHR
ϴ600	90	71	84	66	65	58	79	62	67	55
ϴ300	55	44	52	41	40	36	49	39	41	33
PV	35	27	32	25	25	22	30	23	26	22
YP	20	17	20	16	15	14	19	16	15	11
ϴ200	61	44	46	32	36	32	41	35	40	30
ϴ100	42	32	37	25	24	19	32	23	16	15
ϴ6	13	11	13	11	13	10	11	9	8	7
ϴ3	11	8	10	9	10	9	9	8	7	6
API FL	-	61	-	24	-	19	-	33	-	22
Spurt loss (API FL)	-	12	-	25	-	1	-	35	-	2
HPHT FL	-	26	-	59	-	33	-	29	-	22
Friction factor	2899		2253		2091		2301		1995	
Torque Reduction	-		2220%		2787%		2062%		3118%	

Table 4: Result of tests of AB and C parts.

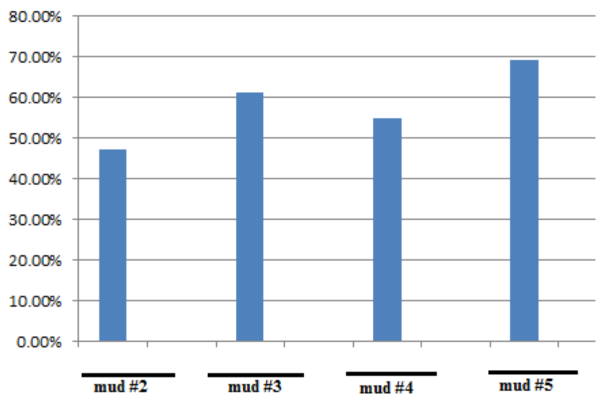

Figure 4: Torque reduction by adding nanoparticles (0.5 and 1% w/w).

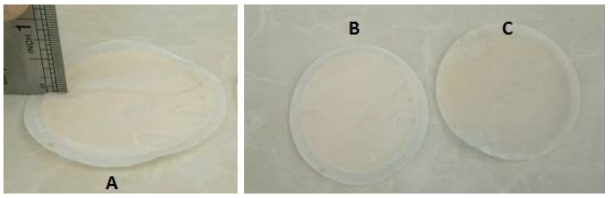

Figure 5: Formed mud cakes: A) unintegrated cake for mud#1 B) mud #2(nano Silica=5% w/w) C) mud #4 (nano Titania=5% w/w).

in the laboratory have indicated that the proposed nano-additives achieved better torque reduction.

The high surface area to volume ratio of nano materials provides them high surface covering ability of these materials between rock surface mediums and metallic tools in the borehole. Also Silica particles have a proper plastering effect that can cover formation surface of the borehole wall and reduce frictional resistance between the pipe and the borehole wall.

The obtained mud cake with using proposed nano materials is ultrathin and stiff mud cake. The homogeneous mud cake with a thickness of 05 mm represents a significant feature of the nano-based fluid (Figure 4).

Nano silica and nano Titania reduced the cake thickness and enhance the structure of mud cake approximately similar to each other Nano Silica and nano Titania reduced mud cake thickness from 15 mm to 5 mm (66% thickness reduction) when are used in 1% w/w (Figure 5).

Stuck pipe test

Laboratory tests indicated that the proposed nano-additives are able to reduce pipe sticking in simple polymeric mud (mud #1) to 100% with adding 1% w/w of each of nanoparticles (nano Silica or nano Titania). Lower filtrate will reduce problem of formation damage in reservoir formations and thinner mud cake helps prevents tendency to pipe sticking which will cause stuck pipe issues. Unique shape and size of the nanoparticles can control their performance in changing the bonding type between the Bentonite particles. The nanoparticles were able to change the linking bonds between the Bentonite particles and due to replacing nanoparticles with the bigger solids less friction on metal surface and even filtrate volume would be obtained. The smaller size of nanoparticles occupies more spaces and therefore more sealing of the pores and less filtration Nano Silica particles due to having plastering effect and covering metallic surfaces could perform this action better than nano Titania (Table 5).

Conclusions

- Using the proposed nano-additives can eliminates problems such as hole pack-off cuttings accumulation in deviated horizontal and extended reach wells mechanical pipe sticking the torque and drag problems and etc.
- Proposed nano-additives can decrease differential pipe sticking in highly permeable/porous formations by depositing an ultra-thin mud cake on wellbore surface.
- Proposed nanoparticles were used in low concentrations and without any need of surfactants assistance in the drilling fluid.
- Wide pores size distribution of applied nano-additives cause filling out the pores Pore plugging is a physical mechanism that is effectively occurred in API/HPHT filtration tests.
- Nano Silica and nano Titania can be used to enhance the properties of efficient WBMs with minimum friction loss of formed mud cakes and high torque reduction.
- Nanoparticles enhance the structure of mud cake by making it smoother and more compacted They do not increase the mud

Properties	mud#6	mud#7	mud#8	mud#9	mud#10
Bulk Sticking Coefficient (K_{sc})	113	1	0	19	0
Average Torque (psi)	143	10	0	22	0
Filtration (cc)	262	148	125	161	133
Filter Cake thickness (H) (mm)	2	0	0	1	0

Table 5: Differential stuck pipe test.

density and mud cake thickness as extra solids (like barite) in the mud.

- Proposed particles mostly fill the micro/nano pores on the mud cake surface leading to smoother more compacted and ultrathin mud cakes.

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15. Recommended Practice for Field Testing Water-based Drilling Fluids.